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# PHOSPHORUS SOURCE APPORTIONMENT SUMMARY: UPDATING THE SAGIS UPPER WYE MODEL

SAGIS Non-Technical Calibration Report for the Upper Wye

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Dŵr Cymru  
Welsh Water



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# DOCUMENT HISTORY

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| REVISION | PURPOSE DESCRIPTION                    | ORIGINATED | CHECKED (DCWW) |
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# DOCUMENT AUDIT

| AUDITOR        | ORGANISATION                                 | DATE       |
|----------------|--|------------|
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# 1. MODELLING THE RIVER WYE SAC

The purpose of this note is to provide an overview of the computer modelling approach being used to develop plans for wastewater investments to help ensure the River Usk achieves water quality objectives for phosphorus. The modelling work is still in progress and subject to the conclusions of NRW's quality assurance.

Most of the upper River Wye catchment is designated as a Special Area of Conservation (SAC) under the Conservation of Habitats and Species Regulations 2017 (referred to as the 'Habitats Regulations'). In January 2021 Natural Resources Wales (NRW) published a report on the compliance assessment for tightened phosphorus targets showing that c67% of water bodies in the River Wye SAC fail to achieve the targets. In response, NRW and Dŵr Cymru Welsh Water (DCWW) have implemented a programme of water quality modelling to develop an improved understanding of the sources of phosphorus within the catchment, and to explore approaches for improving water quality. Note that whereas the term 'phosphorus' is used in this document, the form of phosphorus that has been modelled is known as 'orthophosphate', the form measured and compared with environmental targets. This may be understood to represent the most bioavailable form of phosphorus.

This note focuses on the section of the upper River Wye SAC in Wales (area within the red boundary in Figure 1). DCWW is working with the Environment Agency to update their water quality model for the catchment region situated in England.

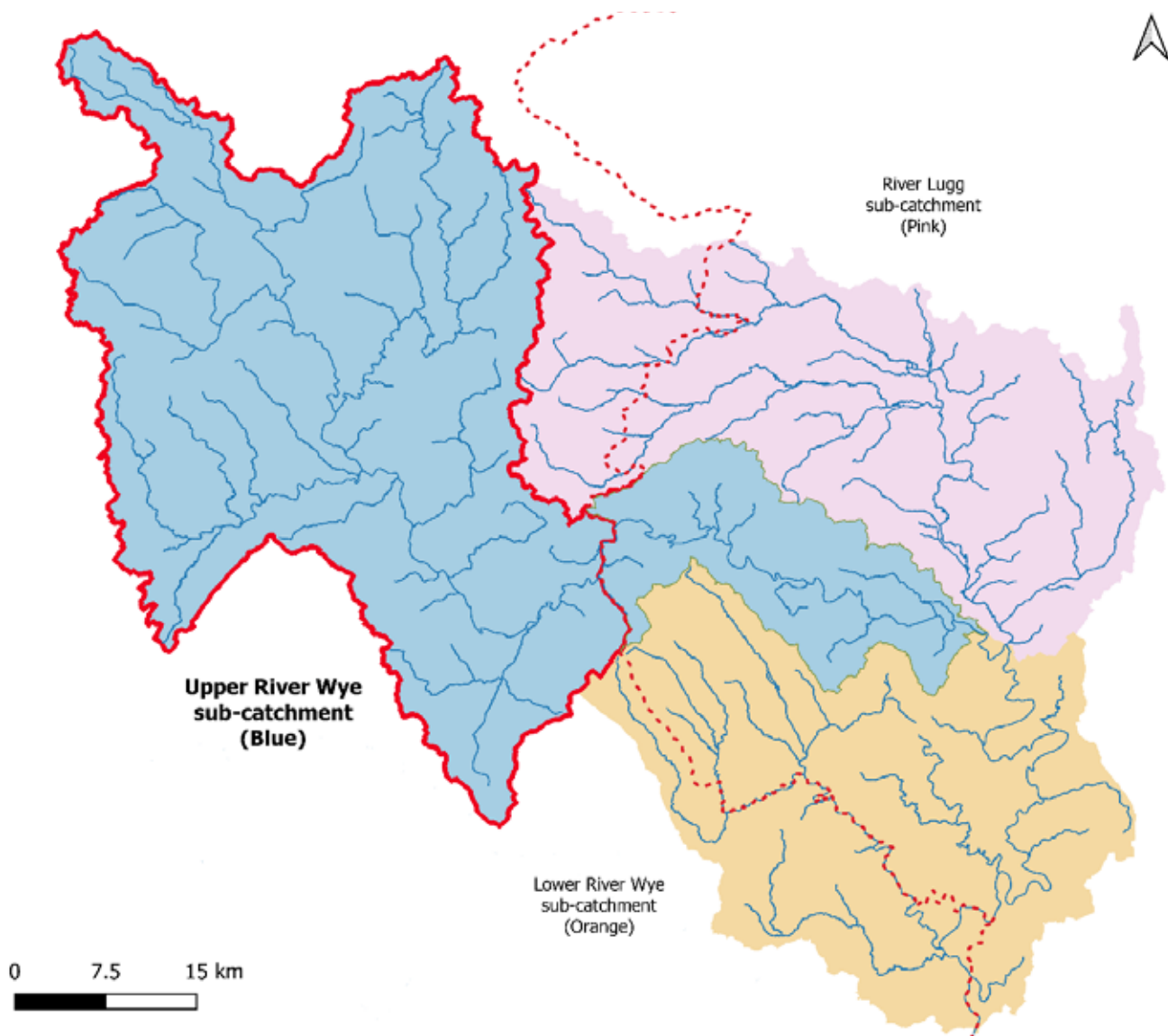


Figure 1 - Map showing upper River Wye (Welsh section within the red boundary)



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## 2. WATER QUALITY MODELLING

Water quality modelling has been used for many years in wastewater planning to assess the effectiveness of controls on point sources of pollution and to help identify those interventions that are likely to be most effective in reality. Modelling helps to provide confidence that measures will deliver the envisaged environmental outcomes.

Computer models, however, provide only a simplified representation of complex natural systems and consequently, their limitations must be considered as part of the process of developing plans of action. Indeed, modelling is most useful when deployed as part of a 'weight of evidence' approach where it is used in combination with information from other sources, including local knowledge and input from other subject matter experts. Key stages in the modelling process include:

- Models are updated and calibrated so that they provide a reasonable representation of recent catchment conditions.
- Important limitations and uncertainties are identified and characterised.
- Water quality improvement scenarios are simulated following regulatory guidance to identify the most effective combinations of measures.

NRW uses water quality models to define new discharge quality permits for DCWW's wastewater point source discharges assets and where necessary to target further monitoring and investigations. Permit conditions for water company assets are subsequently formalised and implemented through normal investment planning and delivery processes. New discharge quality permits for DCWW's assets are subsequently formalised and implemented through normal investment planning and delivery processes.

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## 3. SOURCE APPORTIONMENT GRAPHICAL INFORMATION SYSTEM (SAGIS)

The Source Apportionment Graphical Information System (SAGIS) has been used to create the virtual representation of the upper River Wye. SAGIS is derived from earlier modelling approaches (SIMCAT and RQP) that have been in use in the UK for several decades which have underpinned the investment made by the UK Water Industry in measures to improve water quality. Together with SIMCAT, SAGIS (also known as SAGIS-SIMCAT) is the standard tool used by regulators and the water industry to identify assets where controls on effluent quality are required. The SAGIS build version used in this study was 1.0.7790.19022.<sup>1</sup> The version of SIMCAT was 15.7.

### MODEL DATA

There are two main types of data contained within SAGIS model databases – measurement and sector data (further information is provided in Appendix A):

- **Measurement data** – river flow (for the period 2015 to 2019) and quality (phosphorus) measurements as well as sewage treatment works discharge flow and quality (for the data period 2016 to 2019). A five year period for river flow was used because period statistics are less likely to be impacted by unusual conditions within a single year whereas a four year period for river quality was used due to concerns over anomalous measurements in 2014 and 2015. Where measured effluent quality data was not available a default value of 5 mg/L was applied. For treatment works with descriptive permits, discharge flow was estimated as the population served multiplied by 165 litres per person per day. For other sites discharge flow was based on either measured data or the permitted discharge flow.
- **Sector data** – for inputs from sources other than sewage treatment works.
  - Estimates of diffuse inputs are included in the model by sector as an annual load input by waterbody. Contributions from urban, industry, septic tanks and rural land use (split into arable and livestock components) have been estimated. Forestry inputs have not been estimated. Within the modelling process waterbody loads are distributed across the river reaches in the originating waterbody.
  - Storm Overflows (CSOs) – SAGIS includes representation of inputs from intermittent discharges such as CSOs and storm tanks.

1. Variant of build 1.0.7794.37780

## MODEL CALIBRATION

SAGIS calibration is a process through which the level of agreement between observed and simulated values is optimised. Within the calibration process, the parameters controlling the sector input loads (the total input load) and variability (the variability associated with the total input load) are adjusted along with the determinand decay rate (a parameter representing a combination of effects, including in-river losses due to uptake of nutrients like phosphorus into the environment, deposition to sediment, and chemical transformation).

## MODEL CONFIDENCE

Following the calibration process, the level of agreement between measured and simulated values is assessed. The level of agreement helps to identify locations or regions where modelled values diverge from measured values, and therefore where the model may be inappropriate to support decision making (or at least to identify where there may be uncertainty associated with the outcomes of actions that are supported by model outputs).<sup>2</sup>

For the Upper Wye model the level of agreement between observed and simulated concentrations was evaluated for monitoring locations in England and Wales separately. In Wales, model performance was assessed at 54 locations, with a good level of agreement at 49 locations. Of the five locations where the agreement was not as good, river quality data for two locations was considered unsuitable for characterising model performance due to low sample numbers, data for two locations showed the difference between observed and simulated concentration was not statistically significant (moderate), and with data for one location specifically excluded following agreement by DCWW and NRW. In these cases the model can be used to help target further monitoring and investigation.

## MODEL AUDIT

To provide assurance that the model is robust and can be used as the basis for wastewater planning, NRW has commissioned a quality assurance of the SAGIS-SIMCAT modelling of phosphorus in the river. The aims of the QA were to ensure the models have been built and calibrated in line with agreed guidance; check that the correct water quality targets have been applied at the correct locations, and that the spatial location of model features is correct; identify any discrepancies between the models and guidance and help prioritise any required changes; ensure the outputs from the models have been correctly represented tools to be used for wastewater planning purposes.

In summary, the QA has concluded that the model is in line with agreed guidance and fit for the purpose of informing wastewater planning decisions. A number of lower priority recommendations for model development will be taken forward for review later in the year.

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# 4. MODEL RESULTS

At the assessment location (quantified at water quality monitoring station 50021 which, although situated in England, is less than 2km from the border with Wales), the model shows that, under current conditions, approximately 67kg of phosphorus is discharged from the Welsh part of the upper River Wye catchment on a daily basis. Effluent from sewage treatment works accounts for 23% of the average daily load (kg/d) with rural land use contributing 72%, storm overflows contributing 2% and a further 3% from other sources including septic tanks and urban run-off.

The model shows that under current conditions effluent accounts for 35% of the average phosphorus concentration (mg/l). The concentration and load apportionment are different because inputs from different sources tend to occur under differing river flow conditions. For example, inputs from treatment works occur continuously (i.e. under high and low flow conditions) whereas inputs from diffuse sources tend to occur under higher river flow conditions where there is a higher level of dilution available in the receiving water. This means that, on balance, a kilogram of phosphorus discharged from a treatment works will have a relatively greater impact on the in-river concentration than the equivalent input from diffuse sources.

The modelling also takes account of decay effects which, in this context, represents a combination of influences, including in-river losses due to uptake into the environment, deposition to sediment, and chemical transformation. Consequently the loads at the furthest downstream point are not necessarily equivalent to the total input loads.

The modelled load apportionment information is presented in Figure 2 which shows load apportionment at the water quality monitoring location 50021 (also shown in Figure 2) which situated in the middle of waterbody GB109055037116 that spans England and Wales. Although situated in England the water quality monitoring location is less than 2km from the Welsh border and serves as a convenient reporting location. Note that apportionment will differ at different locations within the catchment.

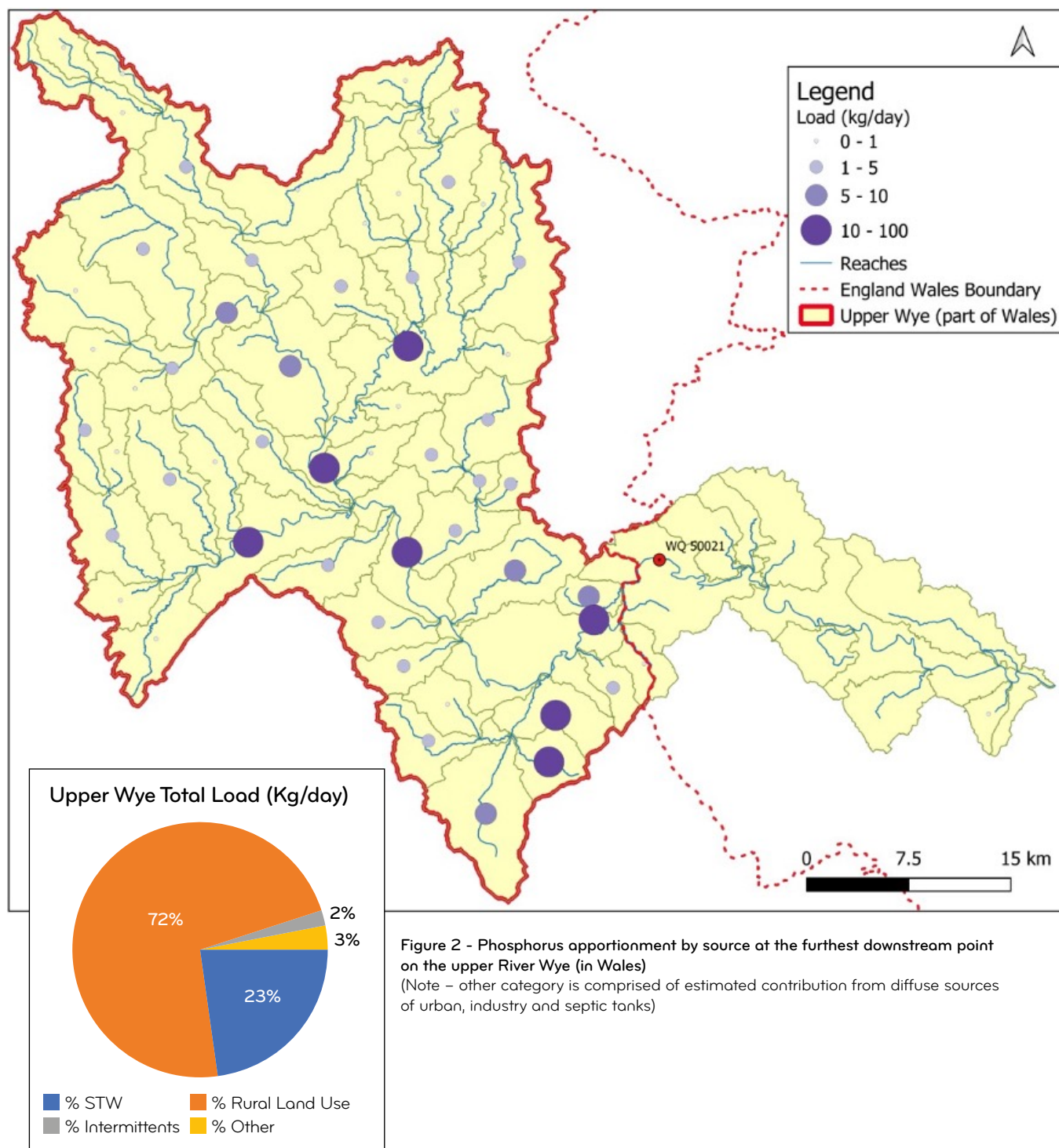
The modelling also takes account of decay effects which, in this context, represents a combination of influences, including in-river losses due to uptake into the environment, deposition to sediment, and chemical transformation. The loads reported are therefore not necessarily equivalent to the total input loads.

SAGIS also provides an estimate of the phosphorus contribution from the storm overflows in the catchment. These were estimated at approximately 2% of the catchment load (at monitoring location 50021). This information is shown in Figure 2.

The availability of water quality monitoring data and sewage treatment works performance data, means that SAGIS modelling provides a robust framework for use in decision-making for wastewater investment planning. In general, estimates of loadings from diffuse sources from other sectors, within SAGIS, have a greater degree of uncertainty.

## 5. SCENARIO MODELLING

The SAGIS model has been calibrated and will be used shortly to test the theoretical impact of changes in effluent quality at a range of catchment treatment works (i.e. 'what if' scenarios). Scenarios are intended to inform on the scale of the challenge of bringing the river into compliance with the targets and the level of investment that may be required.



2. In the model for the upper River Wye SAC the following criteria have been used to characterise model certainty/confidence:

- Good. Where the difference of <0.005 mg/L between observed and simulated values,
- Moderate. Where there is a difference of >0.005 mg/L between observed and simulated values but the difference is not statistically significant (or the number of samples is <12)
- Poor. Where there is a difference of >0.005 mg/L between observed and simulated values and the difference is statistically significant.

# APPENDIX A

## MODEL DATA

There are two main types of data contained within SAGIS model databases, namely, measurement data and sector data. Measurement data are derived from routine monitoring activities, and include river quality information obtained by NRW, river flow information reported at national river flow gauges, as well as effluent discharge flow and quality data. Models are calibrated to the measurement data so that models are expected to recreate (virtually) conditions that span the period of time over which the measurement data was obtained. The model for the River Wye SAC has been developed using phosphorus data covering the period 2016 to 2019.<sup>3</sup> There are two important points relating to how the river quality data are processed prior to inclusion in the model:

- Data obtained as part of reactive pollution monitoring were excluded from the summary statistics to ensure the model data are not unduly distorted by infrequent or random events.
- Several data points not reported as relating to pollution monitoring but that were, nonetheless, found to distort summary statistics, were excluded for the same reason as the reactive pollution monitoring data. The number of data points excluded was, however, small; for Wales 14 out of 1,446 results were excluded (<1%).

The sector data contained within the model databases represent estimates of inputs from sources other than wastewater treatment works, primarily diffuse sources. Estimates of diffuse inputs are included in the model by sector as an annual load input, by waterbody.<sup>4</sup> Within the modelling process these waterbody loads are distributed across the river reaches within the originating waterbody. An occasional consequence is that within the modelling process inputs from certain sectors may be distributed to river reaches in which they are not expected to occur although this tends to primarily affect river reaches situated in headwater locations.

Agricultural input estimates are based on data from the Phosphorus and Sediment Yield Characterisation In Catchment model (PSYCHIC; Davison et al., 2008; Stromqvist et al., 2008), which provides an estimate of phosphorus 'losses' to waterbodies at a 1km<sup>2</sup> grid scale, but which have been aggregated to a waterbody scale for use within SAGIS.<sup>5</sup> Modelled transfer pathways include release of soil phosphorus, detachment of sediment and associated particulate phosphorus, incidental losses from manure and fertiliser applications, losses from hard standings and the transport of all the above to watercourses in underdrainage (where present) and via surface pathways. The model is sensitive to a number of crop and animal husbandry decisions, as well as to environmental factors such as soil type and field slope angle. The PSYCHIC model utilises the mean climate drainage model (MCDM, Anthony, 2003) to calculate the evapotranspiration, soil moisture deficit and soil drainage. The presence of artificial drainage systems the relative importance of different sub-surface drainage pathways are based on the Hydrology of Soil Types (HOST; Boorman et al., 1993) classification. PSYCHIC has been applied across the UK in support of government policy (e.g. Anthony et al., 2005; Gooday et al., 2015) and has also been applied to a number of European catchments (Silgram et al., 2008).

The current phosphorus data within SAGIS for England and Wales is from the PSYCHIC model (Davison et al., 2008) based agricultural census data for 2010.

## REFERENCES

- Comber, S. D. W., Smith, R., Daldorff, P., Gardner, M. J., Constantino, C., & Ellor, B. (2013). Development of a chemical source apportionment decision support framework for catchment management. *Environmental Science & Technology*, 47(17), 9824–32.
- Silgram, M., Anthony, S.G., Fawcett, L. and Stromqvist, J. (2008) Evaluating catchment-scale models for diffuse pollution policy support: some results from the EUROHARP project. *Environmental Science and Policy*, 11, 153-162.
- Strömqvist, J., Collins, A.L., Davison, P.S. and Lord, E.I. (2008) PSYCHIC – A process-based model of phosphorus and sediment transfer within agricultural catchments. Part 2. A preliminary evaluation. *Journal of Hydrology*, 350(3-4), 303-316.
- Davison, P.S., Withers, P.J.A., Lord, E.I., Betson, M.J. and Stromqvist, J., (2008) PSYCHIC – a process-based model of phosphorus and sediment transfers within agricultural catchments. Part 1. Model description and parameterisation. *Journal of Hydrology*, 350(3-4), 290-302.

3. Implies that future conditions will be representative of conditions within the snapshot period. Models are updated and recalibrated on a periodic basis.

4. This is the scale at which diffuse sector inputs can be quantified with reasonable confidence.

5. The substantial uncertainty associated with estimates for individual 1 km<sup>2</sup> grids is well accepted.